Report of Investigations 8367

Relationship of Mineral Habit to Size Characteristics for Tremolite Cleavage Fragments and Fibers

By William J. Campbell, Eric B. Steel, Robert L. Virta, and Michael H. Eisner

UNITED STATES DEPARTMENT OF THE INTERIOR
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BUREAU OF MINES
Lindsay D. Norman, Acting Director

This publication has been cataloged as follows:

Relationship of mineral habit to size characteristics for tremolite cleavage fragments and fibers / by William J. Campbell ... [et al.] [Washington] : U.S. Dept. of the Interior, Bureau of Mines, 1979.

18 p. : ill. ; 27 cm. (Report of investigations - Bureau of Mines ; 8367)

Bibliography: p. 18.

1. Amphiboles - Analysis. 2. Asbestos fibers. 3. Contamination (Technology). I. Campbell, William J. II. United States. Bureau of Mines. III. Title: Tremolite cleavage fragments and fibers, Relationship of mineral habit to size characteristics for. IV. Series: United States. Bureau of Mines. Report of investigations - Bureau of Mines ; 8367.

TN23.U7 no. 8367 622.06173

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CONTENTS

ILLUSTRATIONS

TABLES

(1)

RELATIONSHIP OF MINERAL HABIT TO SIZE CHARACTERISTICS FOR TREMOLITE CLEAVAGE FRAGMENTS AND FIBERS

by

William J. Campbell,[1] Eric B. Steel,[2] Robert L. Virta,[2] and Michael H. Eisner[2]

ABSTRACT

This Bureau of Mines report describes a study conducted to determine the relationship of mineral habit to particle size and shape characteristics for prismatic, acicular, fibrous, and asbestiform varieties of tremolite. Particle measurements were made with the petrographic microscope at X 1,250 and the scanning electron microscope at magnifications up to X 10,000. All of the varieties of tremolite, upon Wiley milling, produced a significant percentage of particles that meet the Federal regulatory criteria for counting as asbestos fibers. However, only the asbestiform variety gave milled particles that fell into a size range of >10 µm in length and <0.5 µm in width; some medical scientists consider this range significant for production of adverse health effects.

INTRODUCTION

In September 1976 the Bureau of Mines established a Particulate Mineralogy Unit to assist local, State, and Federal agencies by establishing precise and workable mineral definitions and by developing improved methods of particulate identification and quantitative measurement (1).[3] Attention to adverse health effects associated with asbestos have been focused on occupational exposure in industries involved in the mining, milling, fabrication, and utilization of asbestos. Now there is increasing concern regarding the effects on industrial employees and the general public from long-term, low-level and short-term, high-level exposure to various elongate mineral particulates present as minor or major constituents in ores, crushed stone, and various industrial minerals. These particulates include both the more common and the asbestos varieties of serpentine and amphibole minerals.

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[3] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

(2)

Asbestos regulatory procedures are based on counting elongated serpentine and amphibole mineral particles at 450 to 500 magnification using phase-contrast microscopy. To be counted as "regulatory," the silicate particles must meet the following size criteria: ≥5 µm in length, ≤3 µm in diameter, and an aspect ratio of ≥3 to 1. These elongate particles are generated by natural growth as fibers (for example, tremolite asbestos) or are produced as cleavage fragments by the crushing and grinding of the common nonasbestos varieties of the amphibole minerals. The present definition of a fiber used by the regulatory agencies does not distinguish between cleavage fragments and fibers produced by natural growth, and existing regulatory practices count all particles that meet the above criteria as equally hazardous. That is, a short-cleavage fragment of a nonasbestos variety amphibole 6 µm long and 2 µm wide is currently counted as being equivalent to an amphibole asbestos fiber 10 µm in length and 0.1 µm wide.

The principal objective of this study is to correlate the size characteristics of particles generated from grinding a typical amphibole mineral--tremolite--with the habit of the mineral. The second objective is to point out that amphibole minerals range in habit from common equant grains to the much rarer asbestiform variety. Regulatory personnel and health scientists should be aware of the strong dependence of particle size and shape characteristics on the mineral's original crystallization habit.

Studies on the biological effects of human and animal exposure to asbestos minerals do not fall within the mission of the Bureau of Mines. However, it is important that mineralogical identification-characterization procedures be applicable to health-related studies. The ultimate goal of all concerned groups--regulatory, medical, and industrial--is to distinguish between particles known to be hazardous and particles for which no adverse effects have been identified so that the workers and general public are protected properly and the domestic minerals industry is not subjected to unnecessary regulations. Measurement of the size characteristics of particles derived from different habits of the same mineral should assist medical scientists in evaluating the various types of elongate silicate particles (2).

PREVIOUS STUDIES

Stanton and Layard of the National Institutes of Health conducted extensive studies on tumor production in rats by introducing various types of particles in the pleural space and observing tumor production over a 2-year span (5). They concluded that implantation of long, thin, durable fibers resulted in tumors in a high percentage of the test animals, and that compositional variables such as trace metals and organics had a significantly lower, if any, effect on tumor probability. Stanton and Layard suggest there is a dimensional range of fibers that is related to tumor probability.

They tested seven durable fibrous materials, each of differing compositions and size characteristics. The order of probability of inducing pleural sarcomas with these test materials ranged from approximately 0 to 100 percent. Fibers of the size range of the International Union Against Cancer (UICC) asbestos standards fell in the 65- to 80-percent probability range. Linear

regression of the tumor probability versus size characteristics indicated that the size class with a diameter of ≤0.25 μm and a length ≥8 μm was the single variable that best correlated to sarcoma.[4] Histologic observations suggested that shorter and thicker particles are not as biologically active.

The relationship of fiber length and diameter characteristics to tumor formation has been the subject of extensive discussion in the occupational and environmental health sciences literature. For example, Wagner (6) states, "Fibers with a diameter below 0.5 μm if injected into the pleural cavity will cause mesothelioma." Wright (7) comments that "Although the fibre diameter should be less than 1/2 μm for tumors to develop also it appears that the fibre must be longer than 10 μm." Davis (3) concluded that "the long fibre theory of asbestos pathogenesis and especially carcinogenicity does, at the present time, appear to be correct but the biochemical reasons why only long fibres should be dangerous are still obscure." Thus, there is agreement, at least among some medical scientists, that long, thin, durable fibers are essential for tumor production in test animals.

In this present study on size characteristics by the Bureau of Mines, emphasis was given to the number of particles in the following size range: length ≥10 μm and diameter <0.5 μm. Durable particles meeting these specifications would be classified as hazardous by most health researchers. There is also general interest in the relationship, if any, between the total number of regulatory particles and those meeting the above criteria for a long, thin fiber. Existing regulatory standards are based on the assumption that there is a constant distribution of asbestos particle sizes ranging from macroscopic to submicroscopic so that the counting methods can be limited to those readily visible by optical microscopy. Whether or not this relationship holds for nonasbestos particles is an important phase of this study.

CRYSTAL HABIT

The amphiboles, a common group of rock-forming minerals in the earth's crust, are found in many geologic settings. They crystallize in a wide variety of habits displayed in a progression from equant or equidimensional to fibrous (fig. 1); a detailed discussion on terminology is presented in Information Circular 8751 (1). All terms shown in figure 1 are general descriptive terms for the crystal habits of grains. There are gray areas between all of these terms; for example, an equant habit means approximately equidimensional, and the break between equant and elongate habits is not precise. However, these terms still have distinctly different meanings and apply to specific particle morphologies.

Traditionally, rock textures are described at a macroscopic or hand-sample level using the types of terms shown in figure 1. A change of

[4] Width rather than diameter is the correct terminology because amphibole particles are rectangular slabs rather than cylinders. The ratio of the width to the height in cross section ranges from approximately 2.5 to 1 to 10 to 1. In general, the amphibole particles are positioned on the slide or support with the widest dimension exposed to view.

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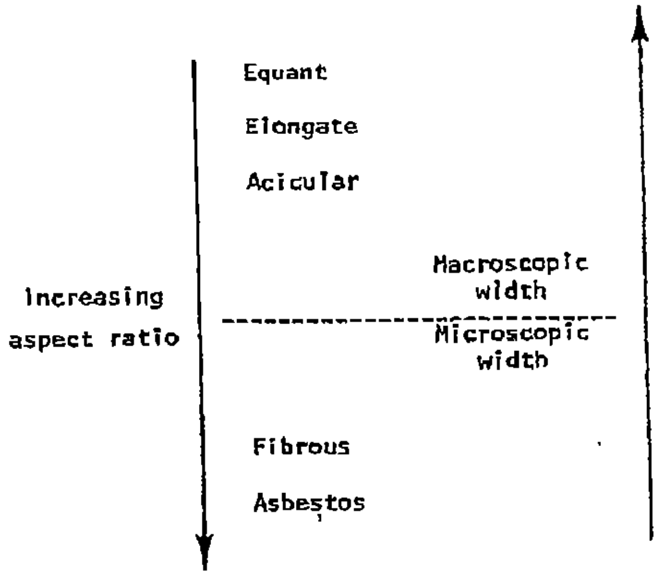


FIGURE 1. - Examples of terminology used to describe grains in hand samples. At some indefinite point between acicular and fibrous habits, the aggregate of grains can still be seen with the unaided eye; however, owing to their thinness the individual grains become very difficult to observe without magnification.

perspective occurs when going from observation with the unaided eye to the high magnifications of the light and electron microscopes. Grains that appear to be fibrous to the unaided eye obviously appear thicker using the microcope and, therefore, might be termed acicular or elongate. It is important to stress that the terms in figure 1 are primarily meant for hand-sample macroscopic examination, and their use becomes much less meaningful once the perspective is changed by using high magnification.

The term fibrous is used in a general mineralogical way to describe any aggregates of grains that crystallize in a needlelike habit and appear to be composed of fibers. The term "thin," as used in this report, means that the width of the grains is difficult to see with the unaided eye. In the terminology in figure 1, "fibrous" has a much more general meaning than "asbestos". While it is correct that all asbestos minerals are fibrous, not all minerals having a fibrous habit are asbestos. Asbestos has properties that make it unique and different from other fibrous minerals and even from other fibrous habits of the same amphibole. The asbestos minerals of commercial importance have the following characteristics:

1. Aspect ratios ranging upward to 1,000:1 or higher.

2. Very thin fibrils, generally less than 0.5 μm in width.

3. Very high flexibility and tensile strength compared to nonasbestos minerals.

4. Parallel fiber growth in veins.

The classic crystal habit of asbestos includes all four of these properties. With the exception of mass fiber deposits, which have reticulated or random direction of fiber growth, all commercial asbestos has these crystal habit characteristics.

FIGURE 2. - Macrophotograph of prismatic tremolite showing the large euhedral grains in a medium-grained marble.

FIGURE 3. - Photomicrograph of thin section of prismatic tremolite under crossed nicols displaying cleavage traces within the very large grain of tremolite. Some calcite can be observed within the grain.

The large aspect ratio, very thin fibers and fibrils, flexibility, and tensile strength are the unique properties that make asbestos commercially valuable. However, there are variations in these properties from mineral to mineral, from deposit to deposit, and even within the same deposit. For instance, chrysotile does not have the tensile strength of crocidolite. The mass fiber chrysotile has shorter fibers than the other forms of "vein" chrysotile, and within a deposit the fiber lengths vary considerably. All of this variation takes place within the bounds of the characteristics of asbestos listed above. It is important to note that not all amphiboles have been found with asbestos habits; for instance, there is no verified occurrence of hornblende asbestos.

PETROGRAPHY OF SAMPLES

Samples were selected for this study to cover a wide range of crystallization habit from essentially equant grains to asbestiform. Where available, approximately monomineralic samples were used. The texture of the prismatic, acicular, fibrous, and asbestos tremolite-actinolite samples can be observed in the macrophotographs and the photomicrographs of thin sections included in this report. Light optical properties of the samples are listed in table 1.

(6)

TABLE 1. - Optical data for tremolite of various habits

Sample	Optical parameters				
	n_α	n_β	n_γ	2V, degrees	Extinction angle, degrees
Prismatic................	1.607	1.618	1.628	[1]87	19
Acicular.................	1.598	1.622	1.626	[2]84	18
Fibrous..................	1.616	1.630	1.638	[2]79	20
Tremolite asbestos 1.....	1.612	1.628	1.638	[1]76	14
Tremolite asbestos 2.....	1.612	1.628	1.638	[1]76	19
FD-72....................	1.610	1.622	ND	ND	ND
FD-275...................	1.598	1.620	ND	ND	ND

ND Not determined.
[1]Calculated values.
[2]Measured values.

The sample in figure 2 from Adirondack, N.Y., is a coarse-grained prismatic tremolite in a medium-grained marble. The prismatic grains of tremolite are approximately 1 to 5 mm wide and 15 to 30 mm long. Prominent striations parallel to the long direction of the grains were observed. A thin section of the sample shows evidence of cleavage planes but no distinct grain boundaries (fig. 3). A few sections with crystals 2 to 3 mm wide and 10 to 15 mm long were picked out of the rock for grinding and subsequent size measurements.

The acicular amphibole sample (figs. 4-5) consists of subparallel crystals approximately 0.05 to 1 mm wide and 0.2 to 8 mm long, with the average grains being approximately 0.15 by 1 mm. Note that the width of most of the grains is visible with the unaided eye. The grains generally have tapering to pointed terminations. The specimen is listed by Ward's National Science Establishment, Rochester, N.Y.,[5] as tremolite even though the chemical composition varied considerably throughout the sample. The chemical composition, determined by the energy-dispersive X-ray spectrographic mode on the scanning electron microscope, varied over a wide range, including magnesium amphibole with a trace of calcium, magnesium-iron amphibole, and calcium-magnesium amphibole, and calcium-magnesium amphibole with a trace of iron. The optical data in table 1 for the acicular sample are only approximate because of the variations in composition. The elongate grains characteristic of the acicular habit are readily visible in the thin section (fig. 5). Although many of these grains have an aspect ratio of greater than 3 to 1 and exceed 5 μm in length, these grains, if released intact during grinding, would not be regulatory particles because of their large width. Extensive preferential breakage parallel to the long dimension would be required to produce particles meeting the regulatory criterion for width.

[5]Reference to specific suppliers is made for identification only and does not imply endorsement by the Bureau of Mines.

7

FIGURE 4. - Macrophotograph of acicular amphibole.

FIGURE 5. - Photomicrograph of thin section of acicular amphibole under crossed nicols.

The fibrous tremolite (figs. 6-7) was collected from a rodingite vein in a Maryland serpentinite quarry. The grains range in orientation from random to subparallel and are approximately 0.7 um to 75 um wide and 50 um to 500 µm long with an average grain being approximately 15 by 80 um. The width of these grains is not visible with the unaided eye; one can only see the masses or bundles of the individual fibers.

The tremolite asbestos samples (figs. 8-9) are composed of fiber bundles ranging from 30 mm to 100 mm in length and approximately 0.5 um to 10 um in width. Asbestos 1, from California, contains a minor amount of fine fibrous talc. Asbestos 2 is a museum sample collected in Rajasthan, India. Both samples are more brittle than the typical commercial asbestos, and neither consistently had the random orientation about the c-axis characteristic of amphibole asbestos.

Samples FD-72 and FD-275 were obtained as fine powders from William E. Smith, Fairleigh Dickinson University.[6] Sample FD-275 was isolated from a sample of tremolite taken from a tremolitic talc ore body; asbestos variety tremolite was the source of FD-72 (4). The FD-72 tremolite was reported by Smith (4) to produce tumors in hamsters using intrapleural injection methods. In contrast, no tumors were observed in the hamsters injected with FD-275. Therefore, comparison of the particle size and shape characteristics of these

[6]The cooperation of Professor William E. Smith, Health Research Institute, Fairleigh Dickinson University, Madison, N.J., is gratefully acknowledged.

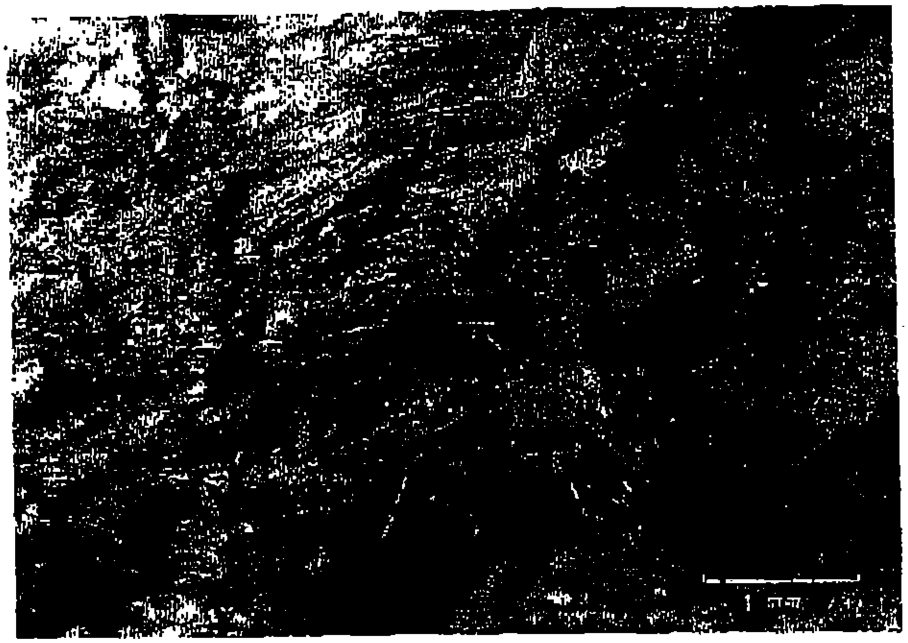


FIGURE 6. - Macrophotograph of fibrous (nonasbestos) tremolite.

FIGURE 7. - Photomicrograph of thin section of fibrous tremolite under crossed nicols showing the interlocking texture of the grains.

9

FIGURE 8. - Macrophotograph of tremolite asbestos 1.

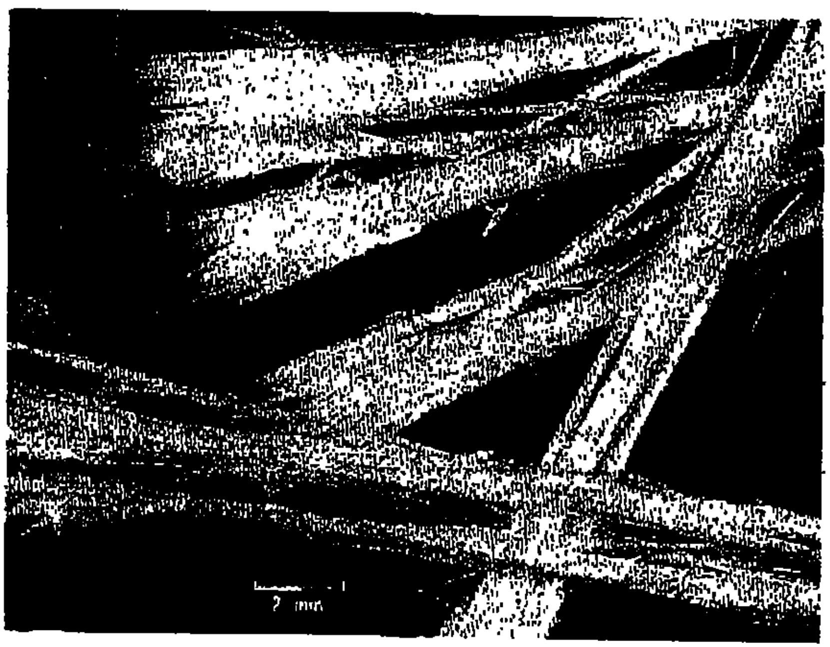


FIGURE 9. - Macrophotograph of tremolite asbestos 2.

FD samples with the particles derived from Wiley-milled tremolites of various habit may provide some insight into their relative biological activity. The UICC amosite standard was included in the scanning electron microscope studies in order to compare our size distribution measurements with published data; no significant differences were noted.[7]

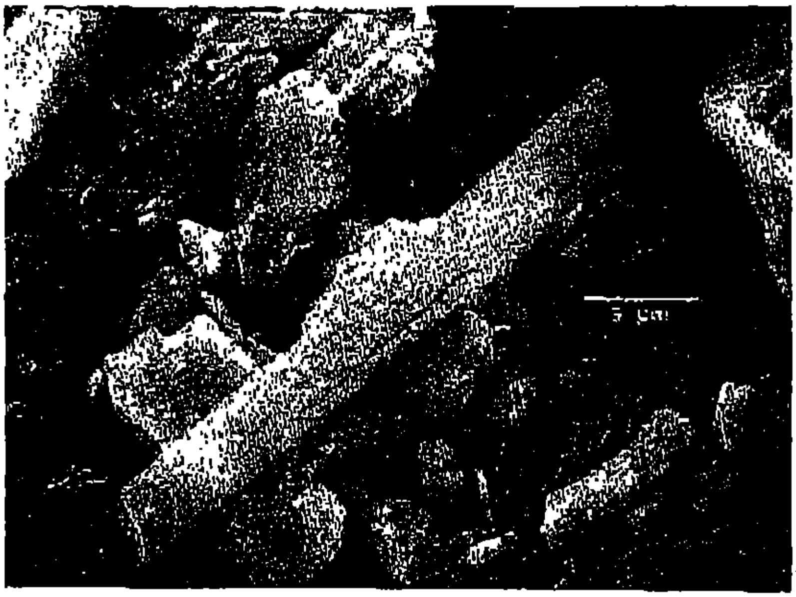


FIGURE 10. - Lengthwise splitting of amphibole grain to form two elongate particles.

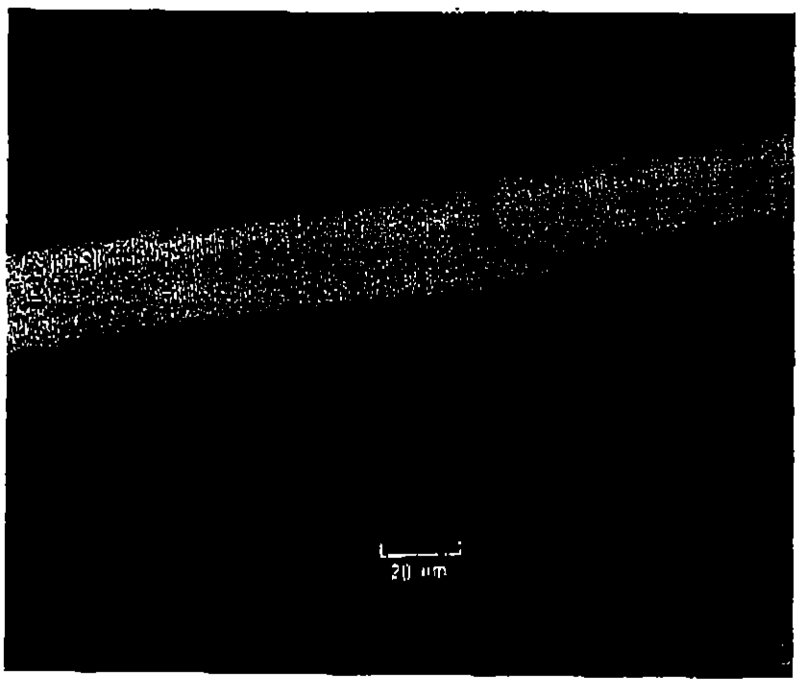


FIGURE 11. - Amphibole breaking perpendicular to the long axis to form two shorter, lower-aspect-ratio particles.

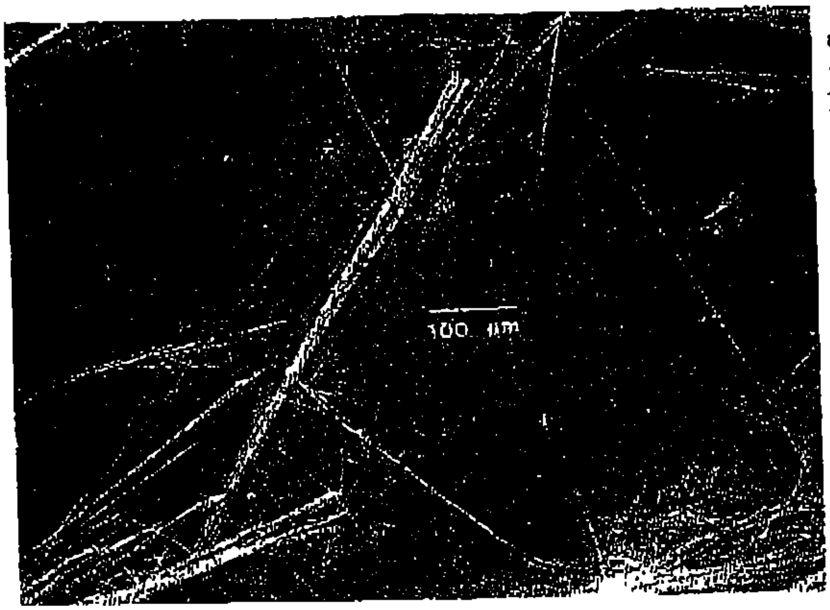
CRUSHING AND GRINDING OF AMPHIBOLES

Important factors controlling the size and shape of amphibole particulates that may be released during mining and milling operations are the original crystal habit of the amphibole grains in the rock, the way in which these grains break or cleave, and the method of crushing. Breakage of asbestos fibrils and fiber bundles appears to be significantly different from that of the nonasbestos forms.

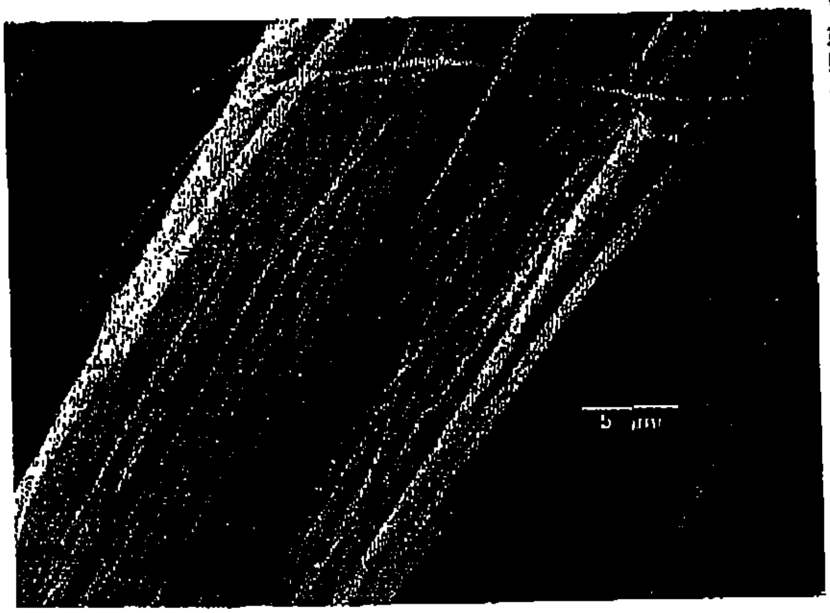
In figure 10 a relatively blocky grain can be seen cleaving lengthwise along the {110} surface to form two elongate particles. This direction of cleavage competes with another direction of breakage or parting on the {001} or {$10\bar{1}$} surface (fig. 11) that is perpendicular to the long direction and produces particles that are shorter and more blocky. In the nonasbestos grains the probability of breaking in the long direction is somewhat higher than that of breaking in the short direction; therefore, elongate

[7]UICC asbestos standards are available from Particle Information Services, P.O. Box 702, Grants Pass, Oreg. 97526.

particles with aspect ratios in the range of 3:1 to 10:1 are produced, together with a few particles of higher aspect ratio.



X 65



X 1,400

FIGURE 12. - Asbestos fiber bundle splitting into thinner, higher-aspect-ratio fibers.

With asbestos the probability of separating the fiber bundles to smaller bundles and to fibrils (see fig. 12) is one or more orders of magnitude greater than that of breakage in the short (perpendicular to the fiber axis) direction. Therefore, thin fiber bundles and fibrils are produced that have aspect ratios of several hundred to 1 and greater.

The next step in this study was to examine the size and characteristics of particles derived from crushing and grinding of tremolites of various habit. Ideally, occupational air samples representative of various mining and mineral processing operations would have been included, however; tremolites are present as trace, minor, or major constituents in talcs, quarry products, etc., rather than as a single mineral. Therefore, it was decided to limit these preliminary studies to essentially monomineralic samples.

To produce the desired particles, each of the tremolite-actinolite varieties (prismatic, acicular, fibrous, and asbestos) was ground by a single pass through a Wiley mill, and the ground samples that passed through a 20-mesh screen were collected. The other samples, FD-72, FD-275, and UICC amosite, were examined for particle size distribution as received.

(12)

MICROSCOPY

Sample Preparation

Grain mounts for the petrographic microscope were prepared by dispersing a small amount of each milled sample in an oil with a refractive index of 1.400 to obtain high contrast. Several mounts were prepared for each sample.

The sample preparation for scanning electron microscopy varied depending on the sample. The following procedure was used for asbestos 1, asbestos 2, prismatic tremolite, fibrous tremolite, and the UICC amosite. A small amount of sample was placed in a vial and then dispersed in distilled water to produce samples with little or no overlap of the particles. The vial was agitated by hand for 30 seconds, and then the larger grains were allowed to settle for 3 to 5 seconds. Approximately 1 ml of solution was withdrawn from the vial and several drops were placed onto carbon-coated scanning electron microscope stubs. These stubs were heated to ~95° C to evaporate the water, and then the sample was carbon-coated.

The acicular amphibole and the two FD samples were prepared for counting by the following method. A small amount of sample was placed in a vial and dispersed in water. The acicular amphibole was agitated by hand for 30 seconds, and the larger grains were allowed to settle for 3 to 5 seconds. About 1 ml of solution was withdrawn from the vial and mixed with about 20 ml of water in the funnel apparatus for the nuclepore filters. The solution then was filtered through the 0.1-μm nuclepore filter. A section of the filter was cut out, mounted on scanning electron microscope stubs, and copper-coated.

The FD-72 and FD-275 samples were prepared similarly except that instead of using hand agitation, it was necessary to place the samples in a low-energy ultrasonic bath for 1 to 3 minutes to disperse the samples.

Particle Counting

Field of view counts were made at X 1,250 with the petrographic microscope. All particles with one dimension of 1 μm or greater were counted. Emphasis was given to counting only those particles identified petrographically as tremolite-actinolite.

Counting was performed on the scanning electron microscope by first randomly selecting an area on the tab at low magnifications (~X 100) and then increasing the magnification to X 500, X 1,000, or X 2,000. This region was photographed, and all particles in the field of view or intersecting only the top and left side of the field of view were counted. The magnification used to define the field of view varied according to the size distribution of the samples; for the asbestos samples the field of view was defined at X 500, and for the FD-72 it was X 2,000. The particles were sized using a scale calibrated with 0.1-μm latex spheres at magnifications ranging from X 500 to X 20,000. On each scanning electron microscope stub several fields of view were counted on the center and edges of the stubs.

Size Characteristics

The primary objective of this study was to correlate the size characteristics of the ground tremolites with the habit of the mineral. The number of long, thin particles (>10 μm long, <0.5 μm wide) in each of the milled samples was of particular interest.

The wide variation in size characteristics is qualitatively obvious in the photomicrographs and scanning electron micrographs for each of the samples (figs. 13-20). Size characteristics are presented in a more quantitative format in table 2. These data represent size measurements on 200 to 400 particles for each sample; for ease of comparison, all data were normalized to 200 particles. All particles with one dimension greater than 1 µm were counted. The particles were placed in six classes--a nonregulatory group, and five groups of increasing aspect ratio that meet the regulatory size criteria. Differences in the data in table 2 for the petrographic microscope and the scanning electron microscope are primarily a reflection of the range of magnification available with the two techniques together with some variations in the sample preparation. Also the measurement error using optical microscopy becomes significant for particles less than 0.5 to 1 µm wide. In general, a larger percentage of smaller particles is counted in the electron microscope. Because of the very limited number of particles measured for each sample, the results should be considered as semiquantitative; however, the conclusions derived from this study are not expected to change significantly with more data.

TABLE 2. - Aspect ratio of particles from milled tremolites of various habits

	Aspect ratio range					
	NR[1]	3:1 to 5:1	>5:1 to 10:1	>10:1 to 20:1	>20:1 to 50:1	>50:1
NUMBER OF PARTICLES USING PETROGRAPHIC MICROSCOPY[2]						
Prismatic	174	13	10	2	1	0
Acicular[3]	173	8	12	6	1	0
Fibrous	114	37	37	11	1	0
Asbestos 1	97	13	26	27	27	10
Asbestos 2	107	7	29	24	26	7
FD-72	142	10	25	14	8	1
FD-275	192	4	4	0	0	0
NUMBER OF PARTICLES USING SCANNING ELECTRON MICROSCOPY[4]						
Prismatic	147	27	20	5	0	1
Acicular[3]	187	7	3	1	1	1
Fibrous	138	30	25	7	0	0
Asbestos 1	78	18	27	34	35	8
Asbestos 2	90	4	18	28	33	27
FD-72	166	9	6	8	9	2
FD-275	195	1	3	1	0	0
UICC amosite[5]	138	2	10	21	21	8

[1]NR designates nonregulatory particles that do not meet the length ≥5 µm, width ≤3 µm, and aspect ratio ≥3 criteria.
[2]Size measurements on 200 particles at X 1,250 with petrographic microscope.
[3]Low-calcium amphibole.
[4]Size measurements of 200 particles with scanning electron microscope. Magnification up to X 50,000 was used where necessary to measure small-diameter particles.
[5]UICC standards were prepared in South Africa by attrition grinding. This grinding was more extensive than used by the Bureau on asbestos 1 and asbestos 2.

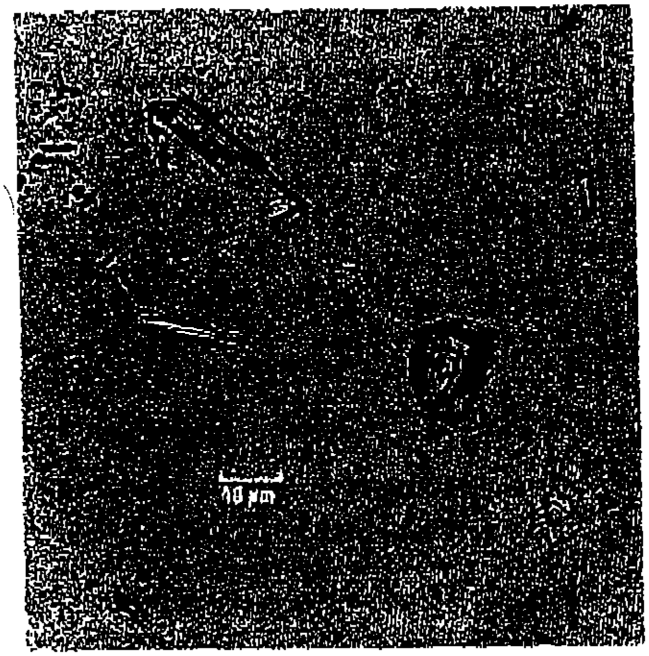


FIGURE 13. - Photomicrograph of particles from Wiley-milled prismatic tremolite.

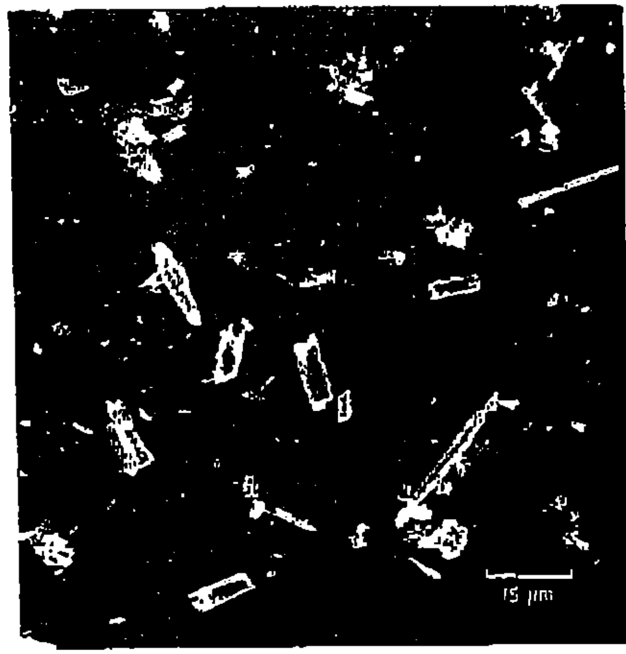


FIGURE 14. - Scanning electron micrograph of particles from Wiley-milled acicular amphibole.

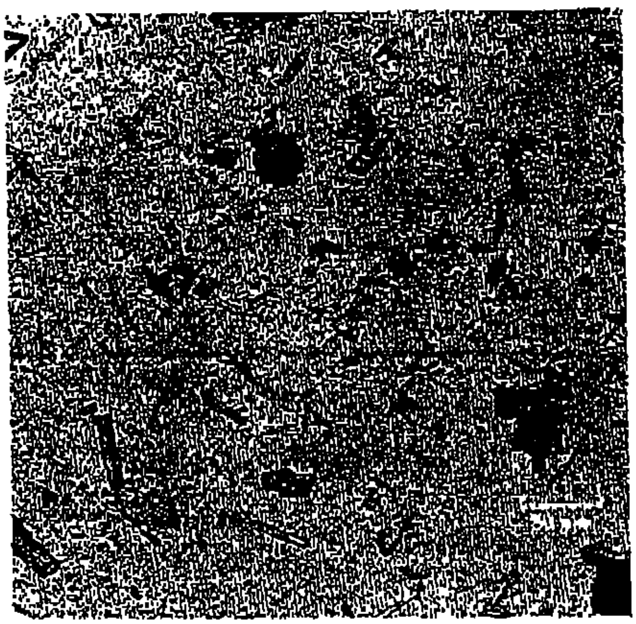


FIGURE 15. - Photomicrograph of particles from Wiley-milled fibrous tremolite.

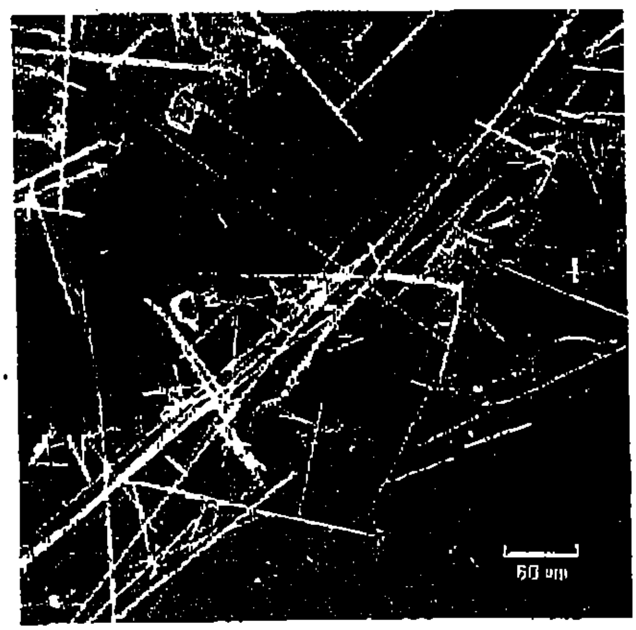


FIGURE 16. - Scanning electron micrograph of particles from Wiley-milled tremolite asbestos 1.

FIGURE 17. - Photomicrograph of particles from Wiley-milled asbestos 2.

FIGURE 18. - Scanning electron micrograph of FD-72 particles.

FIGURE 19. - Scanning electron micrograph of FD-275 particles.

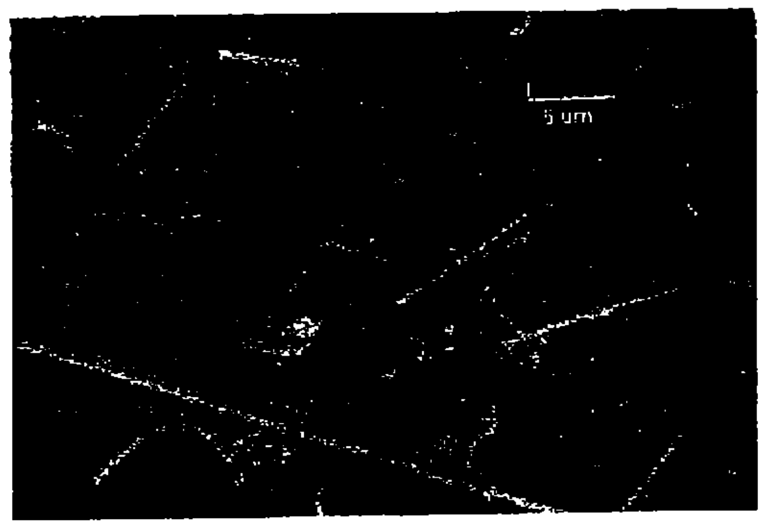


FIGURE 20. - Scanning electron micrograph of UICC amosite particles.

The important feature of the data in table 2 is the very small number of particles with an aspect ratio ≥20 for the prismatic, acicular, fibrous, and FD-275 samples. In contrast, there is a significant percentage of particles with high aspect ratios for asbestos 1 and 2, FD-72, and UICC amosite. This type of size distribution is, as anticipated, directly related to the crystal habit of the samples prior to grinding.

The size characteristics of the samples are organized in a different format in table 3. For this table, particles longer than 10 µm that also met the regulatory criteria were placed in three groupings, depending on the width of the particle. For the prismatic, acicular, and fibrous samples, zero to three particles (based on 200 particles) fell in the 0.5- to 0.99-µm-width group, and no particles were found in the <0.5-µm-width class. In contrast, asbestos 1 and 2, FD-72, and UICC amosite had a large number of long particles in the width ranges 0.5 µm to 0.99 µm and in the critical width range of <0.5 µm. It should be emphasized that the UICC amosite had been subjected to significantly more severe grinding than the asbestos 1 and 2 samples; therefore, no comparison should be made of the size distributions between the two tremolite asbestos samples and UICC amosite.

TABLE 3. - Classification by width of tremolite particles ≥10 µm in length

	Width, µm		
	0.1-0.49	0.5-0.99	1-3
NUMBER OF PARTICLES USING PETROGRAPHIC MICROSCOPY[1]			
Prismatic	0	1	4
Acicular[2]	0	3	8
Fibrous	0	1	26
Asbestos 1	8	11	23
Asbestos 2	14	12	42
FD-72	3	5	10
FD-275	0	0	2
NUMBER OF PARTICLES USING SCANNING ELECTRON MICROSCOPY[3]			
Prismatic	0	1	20
Acicular[2]	0	1	3
Fibrous	0	0	21
Asbestos 1	3	21	59
Asbestos 2	10	16	51
FD-72	4	5	6
FD-275	0	0	0
UICC amosite	6	15	10

[1]Data normalized to 200 particles measured at X 1,250 with petrographic microscope.
[2]Low-calcium amphibole.
[3]Data normalized to 200 particles measured with scanning electron microscope. Magnification up to X 50,000 was used when necessary to measure particles of small width.

SUMMARY

Based on this limited study, there is a relationship between the number of particles of "critical" dimensions, ≥10 um in length and ≤0.5 µm in width, and the habit of the tremolite-actinolite prior to grinding. Although all the Wiley-milled tremolites (prismatic, acicular, fibrous, and asbestos) have a significant percentage of particles meeting the current regulatory asbestos criteria, only the asbestos variety gave long, thin particles of the dimensions established by some medical scientists as necessary to produce adverse biological effects in laboratory animals.

The asbestos regulatory counting criteria were established for air sampling in an occupational environment where commercial asbestos was being mined, milled, fabricated, or installed. Under these restricted conditions, the assumption probably is valid that, for each occupational setting and type of asbestos, there is a relatively constant distribution of particle sizes and shapes, ranging from macroscopic to particles below the limit of resolution of the optical microscope. On that basis, measurement of elongate particles at X 450 reflects the presence of a certain percentage of fibers longer than 10 µm and less than 0.25 to 0.50 um wide. Particles from Wiley-milled tremolite asbestos exhibit a continuum of particle size ranging from very thin to medium width, resulting in some particles with aspect ratios of 100 or greater. In contrast, particles derived from the nonasbestos varieties are skewed toward thicker particles, and the distribution is characterized by the absence of long, thin particles of high aspect ratio.

The existing asbestos regulatory criteria have had an increasingly negative impact on the nonasbestos mining and mineral-processing industries. These criteria equate all particles meeting the regulatory dimensions as equally harmful, whereas there is a significant body of data indicating that only the particles having critical dimensions produce adverse effects in test animals. With minor exceptions, all of the epidemiology and most of the laboratory studies on test animals relate to exposure to commercial asbestos (chrysotile, crocidolite, "amosite," and anthophyllite asbestos). There are no comparable data on exposure to cleavage fragments of the common amphibole minerals found in many mineral-processing industries such as crushed stone quarries and gold and talc operations; currently these operations are being subjected to the same criteria as applied to the mining and milling of commercial asbestos. In consideration of the dual need to establish effective environmental and occupational controls to safeguard the population and the worker, and to avoid unnecessary economic impact on the domestic minerals industry, it is recommended that appropriate experiments be conducted to obtain conclusive data as to the relative effects of the various size particles. The key question to be resolved is the relative biological effect of elongate particles 1 to 3 µm wide as compared to particles of the same length that are less than 0.5 um wide.

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